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The dynamic effects of moisture on the entrainment and transport of sand by wind

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Introduction

Understanding the role of moisture in the aeolian sand transport system is crucial in accurately predicting the mass flux of wind-driven sand. The majority of investigations into the role of moisture in aeolian transport have been conducted in laboratory wind tunnels (McKenna Neuman and Nickling 1989). The findings from these works confirm the conceptual idea of a moisture-dependent threshold and the existence of a critical moisture content above which entrainment is difficult and sediment transport is suppressed. However, comparison of these wind tunnel studies has demonstrated that the findings vary widely (Namikas and Sherman 1995). The paucity of field-based enquiries means that results from wind tunnel studies cannot easily be contextualised in terms of the natural system. Furthermore, only a few studies have explored the time-dependent behaviour of aeolian sand transport in relation to natural moisture levels (see Jackson and Nordstrom 1997). The aim of this research was to investigate the influence of moisture on the temporal dynamics of two aspects of the aeolian sand transport system in the field; (i) entrainment thresholds and (ii) mass flux.

Methods

Experiments were carried out in September 1999 and 2000 at Aberffraw beach on the southwest coast of Anglesey, UK. Three near-surface hot wire anemometers on the upper part of the beach were used to record wind speed fluctuations at 1 Hz. Sediment transport was measured using a *Sensit* grain impact sensor logged at a frequency of 1 Hz. Sediment flux was measured over periods of 10 minutes using a sand trap and gravimetric surface moisture content to a depth of 2 mm was also measured at 10 minute intervals. Two experiments were conducted. The first involved a series of measurements taken during a surface drying episode and was used to determine the effect of moisture on grain entrainment. The second was undertaken during a period of high wind velocity and included a period of surface wetting by rainfall and subsequent drying. This experiment was used to determine the effect of moisture on sediment flux.

Results and Discussion

Establishing a representative threshold

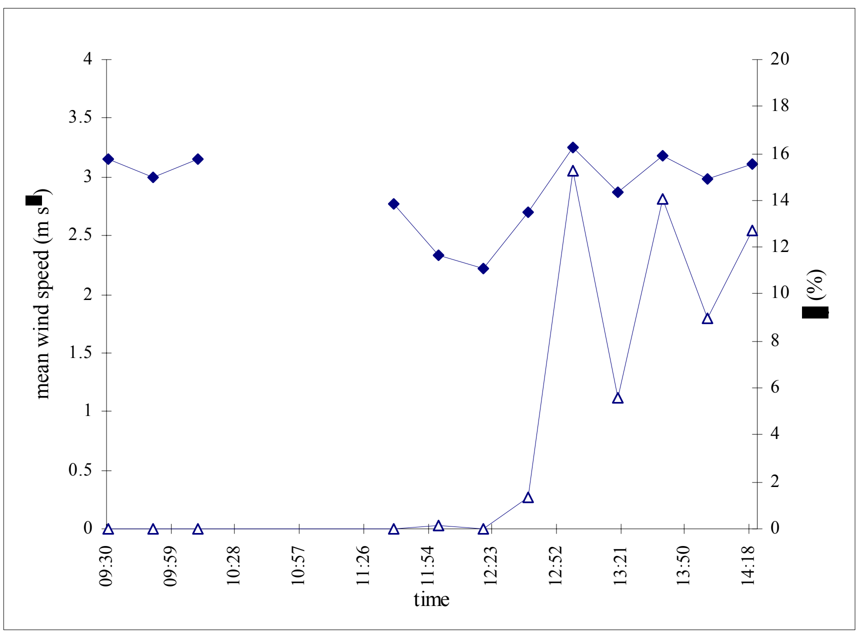
A modification of the time fraction equivalence method (*TFEM*, Stout & Zobeck, 1996) was used on the data from the first experiment to determine the change in critical threshold for entrainment as the beach surface dried. The technique assumes that the fraction of time in which sand transport events occur is equivalent to the fraction of time that the wind speed is equal to or in excess of the threshold value. By converting the *Sensit* and wind speed data to two binary series the threshold value that gave rise to this equivalence was determined from a cumulative frequency plot of wind speed data.

The data were analysed in 20 minute periods with results expressed as the number of sand transport events occurring above the threshold as a percentage of the total number of sand transport events recorded. Overall, the results indicated a poor relationship between the calculated wind speed threshold and simultaneously measured sand transport. In most cases fewer than 50 % of the sand transport events were explained by a corresponding threshold. In an attempt to improve the relationships the data were re-analysed taking into account a time lag between wind velocity and sediment transport, velocity measurement height, undetected transport events, sampling period, shear velocity and turbulence intensity. Results indicated that most sand transport events (67-91%) were explained by a critical threshold analysed using the TFEM based on a 40 second time-averaged wind velocity measured at height of 0.25 m.

Dynamic effects of moisture on entrainment

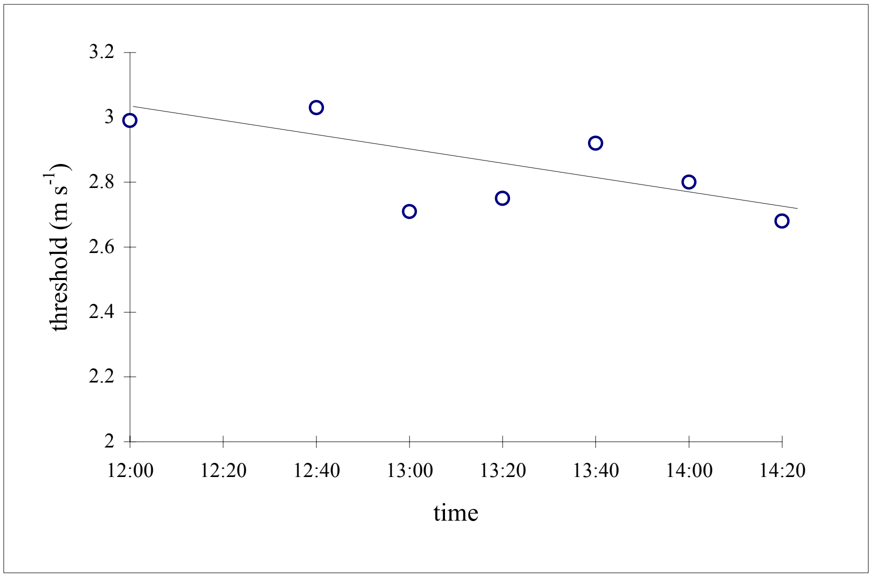
Figure 1 shows data for sand transport (expressed as the intermittency value) and wind speed during a surface drying episode. Figure 2 shows corresponding critical thresholds calculated from the TFEM analysis.

Figure 1: Wind speed (closed symbols) and intermittency value (open symbols)



The data presented in Figures 1 and 2 indicate that from 12.52 onwards the intermittency value responded directly to changes in wind velocity (p = 0.001). Between 12.00 and 12.40 the calculated value of critical threshold reduces, but this is not statistically significant. This lack of a significant change in the threshold over time suggests that once saltation was initiated, the surface conditions did not change sufficiently for any effects to be reflected in the calculated critical values. However, the similarity in wind speeds recorded prior to and during saltation activity suggests that the comparatively high moisture content measured in the early part of the experiment restricted the availability of entrainable material.

Figure 2: Critical threshold values



These results provide evidence of a switch from a system controlled dominantly by moisture, prior to 12:20, to a largely wind regulated system thereafter in which moisture assumes a less significant role. This switch between dominant controlling variables suggests the existence of a wind speed specific moisture threshold for the initiation of saltation activity. Measured data suggest that this threshold lies within the region of 4 - 6 % which is in excess of critical moisture contents specified in previous wind tunnel investigations.

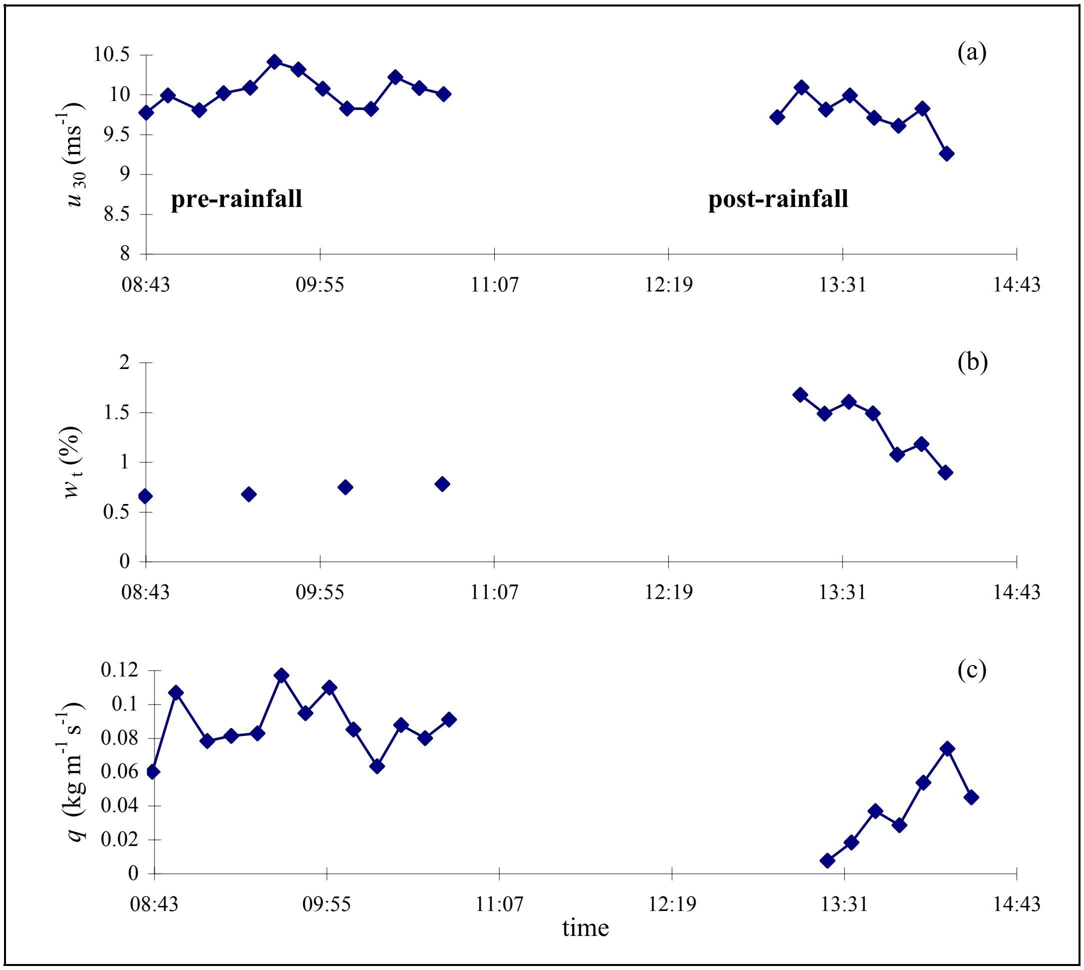
Dynamic effects of moisture on transport

Data in Figure 3 suggest that prior to rainfall sediment flux is responding to changes in wind speed ($p < 0.001$). After rainfall flux is reduced by an order of magnitude but steadily increases to approach pre-rainfall levels. Step-wise regression identified moisture content as the most significant control on transport in this period ($R^2 = 69.3\%$), whilst wind speed was insignificant. This experiment illustrates a switch from mass flux being controlled by windspeed prior to rainfall and regulated by sediment moisture content (for a period of 1 hour) after rainfall. The system appears to be very sensitive to subtle changes in moisture content although it is clear that moisture levels of up to 1.68% are not a barrier to aeolian transport.

Conclusion

The experiments have demonstrated the sensitivity of aeolian sand transport to small changes in moisture content. There is good evidence for the existence of a wind speed specific and moisture threshold, with a decrease in moisture content of the order of 1 - 2 % resulting in the initiation of entrainment. The sensitivity of mass flux to moisture changes of the order of 1 % was also shown. Recovery in the mass flux record, following light rainfall, accord swith a decrease in moisture content and not with fluctuations in wind speed, as found prior to rainfall. The aeolian sand transport system is conceptualised as responding to time-dependent shifts or ‘switching’ between wind speed and surface moisture as the main controls on saltation activity.

Figure 3: Records of measured system parameters before and after rainfall: (a) wind speed, (b) trap moisture content, (c) mass flux rate



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